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KENAF (Hibiscus cannabinus L.) AS A FIBER CROP

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CONTENTS

KENAF (Hibiscus cannabinus L.) AS A FIBER CROP

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Kenaf, Hibiscus cannabinus L., is perhaps the fiber plant most widely cultivated for local consumption in India (33).1/ Jute is produced there in much larger quantities than Kenaf fiber, but the latter is consumed locally in larger quantities. Except in the Provinces of Madras and Bengal, where it is grown in pure stands, Kenaf fiber is usually cultivated as a mixed or border crop. For many years, mills in India have been spinning and manufacturing the fiber into gunny sacks. One of these mills is located at Bimlipatam, and the fiber has come to be known as "Bimlipatam jute." The plant has also been commercially exploited in Java, where the fiber, "Java-jute," is woven into sacks for use in the sugar industries.

Considerable interest in Hibiscus cannabinus has developed in Russia during the past few years. Reports state that 32,500 acres were in production for fiber in 1935 (64). Work on this plant in Russia has been directed toward determining its cultural requirements, developing methods of extracting the fiber, and adapting processes for spinning and weaving the fiber. In addition to the above-mentioned countries, the plant is also grown for fiber in Persia, Réunion, Senegal, Nigeria, Natal, and Egypt.

From most reports, the fiber of Hibiscus cannabinus appears to be similar in chemical composition and physical properties to jute and seems to offer an excellent substitute for ordinary jute. Consequently the available literature was reviewed in order to accumulate the most pertinent knowledge of the culture of this plant, the retting practices followed, and the properties of the fiber. Owing to our limited experience with H. cannabinus in the Western Hemisphere, a comparative evaluation of the material presented was not possible. The summation of the available literature may be, however, of some aid in future investigations of the development and exploitation of this plant in Latin America.

Although statements made in some cases are rather confusing and contradictory, one must remember that the data here reported have been compiled from widely separated locations that have greatly different soil and environmental conditions.

BOTANICAL CLASSIFICATION AND DESCRIPTION

Hibiscus cannabinus, usually an annual but sometimes a perennial plant, belongs to a large genus containing fiber-yielding species. The genus Hibiscus is in the family Malvaceae, of which cotton (Gossypium spp.) is probably the most important member. The Hibiscus genus is characterized by

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1/ Underlined numbers in parentheses refer to Literature Cited, page 33.

plants that are tall shrubs, distinguished by their large showy flowers, the Rose Mallow (Hibiscus moscheutos L.) and okra (Hibiscus esculentus L.) being representative American species. The plants of this genus abound in practically all countries, and to find a fiber list that does not include from one to several species is difficult.

The most valuable species of the genus is, according to Dodge (12), Hibiscus cannabinus, which is a native of the East Indies; Pole-Evans (52), Holmes-Smith (29), and Michotte (44) all state that the plant is native to Africa, whereas Tobler (59) says its home is Asia and Australia.

Miyake and Suzuta (45) have compiled a list of 129 world-wide names which have been given this plant. According to Wiesner (67), the Sanscrit name for the cultivated plant of ancient India, which produced Deccan hemp, was "nalita." According to Roxburgh (55), who gave the first accurate information on Hibiscus cannabinus fiber, the source plant is known in Western India as "Ambari" (hence the names Ambari fiber and Ambari or Ambaree hemp), whereas in Madras it is known as "Palungi," and in Bombay as "Deccan hemp." Dymock, Warden, and Hooper (16) also mention the names for this plant as "patsan" in Hindustan and "Mesta-pat" in Bengal. In Persia this fiber plant is also called "Kanaff." Many of the names, according to Horst (31), such as "Indian hemp," "brown hemp," "Bombay hemp," and "Roselle fiber," were names for mixed-fiber products that were obtained not only from Hibiscus spp. but also from Cannabis sativa, Crotalaria juncea, Abelmoschus spp., Urena spp., etc. At the beginning of the twentieth century, the pure fiber of H. cannabinus was called "Gambo hemp" or "Bimlihemp" (a shortened form of Bimlipatam hemp), and the name "Java-jute" had come into use.

In addition to the above names, the plant has also been called "wild stock rose," "teel," "wild saur," "hemp mallow," "Sunn Okro," "hemp-leaved Hibiscus," "Kanaf," "bastard jute," "Deccani hemp," "Deckanee hemp," and "Deckanse hemp." Among some of the other names mentioned, the fiber products have also been called "Mesta fiber," "Dekanee hemp," "Jute of Madras." "Bimlipatam jute," and Bimli-jute."

There appears to have been considerable nomenclaturial synonymy of this plant, since both Hochreutiner (27) and the Index Kewensis (37) presented lists of the following synonyms:

Synonyms according to Hochreutiner	Synonyms according to Index Kewensis
H. vitifolius Mill.	H. aspera Hook.
H. tripartitus Forsk.	H. congener Schum. and Thonn.
H. radiatus Cav.	H. obtusatus Schum.
H. cannabifolius Stokes	H. radiatus Sieber
H. unidens Lindl.	H. verrucosus Guill. and Perr.
H. congener Schum. and Thonn.	H. vitifolius Mill.
H. Lindleyi Wall.	H. Wightianus Wall.
H. verrucosus Guill. and Perr.	
H. Wightianus Wall.	

Synonyms according to Hochreutiner - Continued
H. asper Hook.
H. Mechowii Hoffm.
H. Acetosella Welwitsch
Ketmia glandulosa Moench.
Furcaria Cavanillesii Kostel.
Abelmoschus congener Walp.
Abelmoschus verrucosus Walp.

In addition to the above synonyms, Michotte (44) lists Hibiscus aculeatus G. Don. and H. radiaxus Sieb.

Royle (56) gave the following botanical description of the species Hibiscus cannabinus L.:

> "Herbaceous annual of about three months duration. The stem is straight and simple, of from 3 to 7 feet in height, with here and there a few inoffensive prickles, otherwise smooth. The leaves are spreading, alternate, with long, slightly prickly footstalks; all are smooth, with the margin serrated; but the lower leaves are heart-shaped; those about the middle of the plant 3-, 4-, 5-lobed, with lanceolate acute lobes; while the leaves at the top are simply linear-lanceolate. Stipules awl-shaped. The flowers are solitary, with short peduncles in the axils of the leaves; very large; of a pale sulfur color, with a deep purple center. Of the double calyx, the outer is 7 - 8 leaved, each subulate, spreading, and inserted near the the base of the inner calyx. This is 5-cleft, division sharp pointed, bristly, and glandular near the margins, and with a large gland near the middle of each division. The stamens numerous, with their filaments united into a hollow column. Anthers one-celled, bursting by a transverse chink. Styles equal in number to the ovaries, and rising through the staminal columns. Carpels joined into a 5-celled, five-valved capsule, with a few seeds in each cell."

Varieties

Until 1911, when Howard and Howard (33) selected and described five varieties comprising eight agricultural types, the type of plant always referred to in the literature was the green-stemmed type with divided leaves, which was quite prevalent, according to those writers, in Northern India. Hooker gave the following description of this type of Hibiscus cannabinus (30, v. 1, p. 339):

> "Annual or perennial, prickly, stem glabrous, lower leaves entire, upper lobed, mid-nerve glandular beneath, peduncle very short, bracteoles 7 - 10 linear, shorter than the calyx, sepals glandular.
>
> Stem glabrous, prickly. Lower leaves cordate, upper deeply palmately lobed, lobes narrow, serrate; petiole prickly, lower much longer than

the blade. Stipules linear, pointed. Peduncles axillary, very short. Sepals bristly, lanceolate, connate below the middle, with a gland at the back of each. Corolla large, spreading, yellow with a crimson centre. Capsule globose, pointed, bristly. Seeds nearly glabrous."

Hooker also mentioned a form with simple leaves and, according to Howard and Howard, this was the only allusion in all literature to the occurrence of distinct morphological types in this species until they selected the five varieties in 1911. They presented the following botanical composite description of the five varieties:

"Annual, leaves midnerve glandular beneath, petiole prickly, long; stipules linear, pointed; flowers axillary, open for a few hours only; peduncles axillary, very short; epicalyx shorter than the calyx, stiff, consisting of 7 - 10 bracteoles connate below free above; calyx connate below free above; sepals bristly, lanceolate, with a gland at the back of each; corolla large, spreading, thickened below, very thin above; capsule globose, pointed, bristly; seeds nearly glabrous."

The main differences noted by them between the five varieties and eight types were as follows:

Variety simplex

Type 1. Stems purple; leaves entire with purple petioles.

Variety viridis

Type 2. Stems green; leaves entire with green petioles.

Variety ruber

Type 3. Stems red below, greenish above; leaves divided with green petioles.

Variety purpureus

Stems purple; leaves divided with purple petioles.

Type 4. Late, stems very tall and slender; leaves with narrow lobes of a diffused purple color; petioles purplish.

Type 5. Early; stems short and robust; leaves green with broad lobes.

Variety vulgaris

Stems green; leaves divided with green petioles.

Type 6. Plants very early.

Type 7. Plants late; seedlings with reddish stems.

Type 8. Plants late; seedlings with green stems.

These authors found that Types 1 and 2, with simple leaves, were similar in habit, though dwarf in form as compared with the rest, and had a strong

tendency to throw out from the base numerous stout branches which grew parallel to the main stems. They observed that Type 5 was an intermediate form between the above and Types 7 and 8, in which the tendency to branching was less marked, and in which the thin short side shoots arose not at the base but were more evenly distributed up the stem. Types 3, 4, and 6 were similarly straight tall forms, in which the side shoots of the edge plants were thin and weak, and in which practically no branching took place in the interior of the plots. These authors recommended the last three types, with long clean stems, for fiber purposes. Van Gorkom (20), from his observations, also noted that the green types of Hibiscus cannabinus were much better than the red for fiber production.

Howard and Howard (33) noted that in vigor and growth period of the eight types there were wide differences that were of importance from an economic point of view. They found that Type 4 was exceedingly delicate, very sensitive to waterlogging, and that it set very few seeds even when grown under the most favorable conditions. Its growth period was quite long, and it flowered only after the other types had ripened some seed. Germination was slow, and the seedlings were small, delicate, and very slender. They observed also that in spite of its tall unbranched stems, these defects rendered this form useless as a fiber plant. Type 5 showed similar defects but to a lesser degree.

Type 6 was the earliest of all the types, and Howard and Howard (33) observed that its seeds ripened and it began to dry up while the others were flowering. This reaction, according to them, combined with its general vigor and tall unbranched habit, renders it of use as a rapid-ripening fiber plant. They stated that Type 3 was the most promising from the point of view of general vigor and its capacity to grow and to set seed under comparatively unfavorable conditions. It was a midcrop form and corresponded in growth period to Type 7. In addition to the above differences in habit of growth, Howard and Howard also presented differences existing in leaves, color, and seedling characteristics of the various types. With regard to the last-mentioned point, they found pronounced differences among the seedlings and young plants of these varieties. They pointed out that these differences are important from two points of view. In the first place, they enable the production of uniform fiber, and, secondly, the production of pure seed is a comparatively easy matter. The differences among the seedlings and young plants of the various types of this crop enable a pure culture to be maintained without much trouble. Most of the stray plants that arise from accidental admixture or from cross pollination, according to them, can be detected by the differences they show in the seedling stage. Any which escape being pulled out at the time of the first rogueing, may be detected before the crop is a foot high.

Horst (31), in Java, obtained seed from India, of seven types of Hibiscus cannabinus selected by the Howards. He studied the plants grown from this seed in an effort to determine which of these types were grown in Java and how adaptable they were to different locations in that country.

His conclusions as to the best types of Kenaf for fiber production were in close agreement with the opinions of Howard and Howard. From his study, he strongly recommended the green varieties viridis (Type 2 of Howard and Howard, with entire leaves) and vulgaris (Type 8 of Howard and Howard, with divided leaves). He states that the variety viridis is grown in the eastern part of Sumatra and is much liked for cultivation, whereas in West Java, the purpureus variety, the red-stemmed type, is popular. The green variety vulgaris, according to Horst, is the most popular variety grown in Western Java after the variety purpureus.

In speaking of the varieties of Hibiscus cannabinus, Horst pointed out that not only can the varieties be distinguished from each other by color and leaf form but also by the blossoms and later the seed. He stated that even the capsular fruits have their special marks of distinction, and the darker the color of a plant, the darker also are the flowers, fruits, and seeds; with some care one can tell from the dried fruits whether they belong to red or green plants.

In a study of the morphological peculiarities of 20 samples of Hibiscus cannabinus from Persia, in connection with data derived from special observations on the growth and branching of these samples under different conditions, Berland (3) showed that this Persian stock consisted of a number of strains, representatives of the variety vulgaris, differing from one another by the length of their growth period, by habit of growth and branching, and by some other less important peculiarities that were closely connected with the length of the vegetative period.

All the forms, comprising the original Persian stock, were divided by Berland into four large groups, each distinguished by peculiarities considered most important from a practical standpoint. The vegetative period of the first group ranged from 90 to 110 days; that of the second, from 110 to 120; of the third, from 120 to 130; and of the fourth, from 130 to 150 days.

Budugjan (7), in an attempt to establish those correlations that, owing to their genetic nature, are constant under different conditions of environment, reported the examination of 18 varieties and 108 lines, together with 53 commercial varieties from all the main regions of cultivation. A total of 7,600 plants was investigated. The results obtained showed strong positive correlation of height of attachment of the first capsule with length of the vegetative period, length of stem and length of petiole; negative correlation of length of stem with tapering; somewhat less marked negative correlation of total weight and length of stem with percentage of bast; and slight positive correlation of height of the first capsule with the number of internodes. No correlation was observed between either the height of the first capsule and the tapering, or length of the leaf lobe, or lower diameter of the stem. The author pointed out that the strong correlations might provide means of improving the plant for fiber purposes by selecting in the field for one or two of the most obvious of the characters, such as height of the first capsule and length of the stem.

Howard and Howard (34) also noted that there were considerable differences in growth period among the various varieties named by them. They observed some were early, others were very late, and some were intermediate types. The earlier types set seed well and did not suffer from "wilt," due to relatively high moisture content of the soil; whereas the late sorts, on the other hand, set seed with difficulty and readily died of "wilt." These differences in time of maturity and in susceptibility to "wilt" became explicable, according to the work of the Howards, when the root systems were compared. They found that the roots of the early types branched near the soil surface and had few laterals on the lower portion of the taproot. In these cases, aeratión was sufficient, and there was no "wilt." The late types, however, had a large portion of the laterals on the lower part of the main taproot, with the result that aeration became more difficult and "wilt" was much more frequent.

In Hibiscus cannabinus, Howard and Howard (34) found the taproot penetrated the soil deeply and the development of the laterals was not concentrated near the surface. They observed that the root system in this species was much deeper than in the case of H. sabdariffa. In the latter species, "wilt" was not a problem even in wet seasons, but in the case of H. cannabinus, the plants were very subject to "wilt."

The work of Popova (53) showed that the differences in strains in Hibiscus cannabinus are in the height of the plant, the thickness of the stem, the color, and in the leaves and flowers. He found strains with large and small capsules, and with large and small seeds. He noted that the strains from Central Asia were most frequently midseason ones, with large capsules and large seeds, whereas the bulk of the strains from Persia were small-capsuled and small-seeded, with a later maturity than that of the strains from Central Asia. The capsules of the Persian strains were observed to dehisce at maturity, whereas those of the Central Asiatic strains were nondehiscent.

The number of seeds appeared to be different in the various strains. In the late Persian strains, in every lower capsule 10 to 15 seeds were found; in the midseason strains from Central Asia, 16 to 19 seeds were found. Also there was a regular increase in the number of seeds toward the top of the plant. Thus, for instance, the uppermost capsules of the late Persian strains contained 22 to 27 seeds, whereas there were only 10 in the lower ones.

Popova further noted that under the conditions of Central Asia, Kenaf was a self-pollinated plant. Flowering proceeded in sequence from bottom to top of the main stem. He found in the midseason strains the flowering of one plant continued 50 days; in the late strains it took only 20 to 30 days; whereas the early strains flowered for 15 to 20 days. He also observed that the node at which the first flower unfolded and the length of the period of vegetative growth of Hibiscus cannabinus were closely connected. The earlier the strain, the closer to the ground the first flowering node was

located; in the late strains, however, flowering began on the upper nodes. The period of most intensive flowering was found to be connected with a marked decrease in the longitudinal-growth rate of the stem. H. cannabinus attained its maximum rate of growth in height before flowering; when flowering set in, growth diminished, and this decrease was most evident during the time of full bloom.

He further observed that the period of maximal growth was determined by the peculiarities of the strain. As a rule, the best growth in all strains of Hibiscus cannabinus took place before flowering. Thus, the period of flowering determined the maximal growth. In early strains, the period of maximal growth set in earlier than in midseason and late strains. The flowering period was the turning point in the curve of growth, after which growth began to decrease.

Polymorphism in Hibiscus cannabinus leaves

In addition to the entire and very broadly lobed leaves of certain varieties of Hibiscus cannabinus, Cook (10) observed that there were others with deeply divided narrow leaves and some with leaf blades separated to the base into narrow digitate segments. All these variations in leaf forms of Kenaf, according to Cook, were curiously paralleled with those of cotton, Gossypium spp. Further similarity was found by him in the fact that, in Egypt, a type of Kenaf with lobed leaves produced entire leaves at the base of the stalk. This, he stated, also happens with the narrow-lobed "okra" varieties of Upland cotton: "The Hibiscus leaves show a very abrupt transition from the broad, simple form of leaves on the lower part of the stalk to the narrow, deeply lobed form on the upper part (fig. 1); this abrupt change in the characters of the leaves seemed the more worthy of notice on account of the fact that Mendelian segregation of the broad and narrow forms of leaves has been found to occur in the second generation of crosses between varieties of cotton representing two corresponding types of leaves. The hemp (H. cannabinus) plants with two kinds of leaves represent a segregation of characters among the internode members of the same plant."

The transition in leaf form in Hibiscus cannabinus was found by Cook to be usually quite abrupt, though the leaves close to the point of transition were often slightly different from others of the same class. A premonition of the change was found in the larger marginal teeth of the last of the undivided leaves, or in the last simple leaf, which sometimes had a prominent angle on one or both sides. A more definitely intermediate condition appeared when a leaf was divided on one side but not on the other. In such cases, the difference between the two sides of the leaf was pronounced, so that the change from the entire to the lobed condition was still quite abrupt in comparison with the very gradual changes shown in many plants in passing from the long basal leaves to those of the upper part of the stalk.

With regard to the polymorphism exhibited in Hibiscus cannabinus leaves, Cook stated: "It is difficult to imagine that any practical advantage can be

secured by the plants by changing the form of the leaves thus abruptly part way up the stalk. Yet it is possible that the different forms of the leaves may be connected with the fact that there is a difference of function among the internodes of the stalk. The internodes of the upper part of the stalk produce fruit or fruiting branches, while those of the lower part do not.... In Deccan hemp [H. cannabinus] ... the fruits are borne directly at the axils of the main stalk without the intervention of fruiting branches. It may be that the divided leaves indicate in advance the internodes that are to produce flowers and fruit. Change of leaf form marks the approach of the fruiting condition in such plants as Hedera helix and Ficus repens, but in such cases the change of leaf forms does not occur on the same axis of growth."

Pollination

In striking contrast to its close relative Hibiscus sabdariffa, natural cross-pollination occurs in H. cannabinus, according to Howard and Howard (33). A study of the flower structure, they stated, showed "that the opportunities for cross-pollination by insects are very great." Horst on the other hand, states (31) that anthesis lasts only 6 to 10 hours, after which the flower folds up and on the following day falls. He noted that self-pollination is favored by the structure of the flower, stating: "The anthers are so close to the stigmas that self-pollination is inevitable; in fact, I found the stigmas in unopened flowers already covered with pollen."

Ustinova (61), in a study to determine the percentage of natural cross-pollination in the five varieties named by the Howards, found that the varieties differed in their tendency to natural crossing, it being least in Hibiscus cannabinus var. viridis. This variety was found to be entirely self-pollinated. In the variety vulgaris, cross-pollination varied from 2.58 to 3.92 percent in its different forms. In a previous study (60) she found that irregularities in the structure of the flowers of H. cannabinus var. vulgaris were frequent and variable. Although the percentage of staminate and pistillate flowers was not large, nevertheless, they did exist. She observed that the tendency for irregular development in the organs of reproduction in the different geographical races of Persian H. cannabinus was variable and progressively increased from the early maturing to the later maturing races. The percentage of undeveloped ovaries in this species was found to vary according to the race of H. cannabinus but was in the limits of 5.5 to 9.5 percent.

Howard and Howard (33) observed that the flowers of this species opened in the early morning before daybreak and began to close about midday. The closing of the flower was very rapid and, according to them, before sunset the partially withered corollas were twisted. During the night, still further twisting of the corolla took place, giving rise, as they stated, "to the cottage loaf shape of the withered flower."

The method of pollination was described by Howard and Howard as follows: "When the flowers open, the stigmas are at the mouth of the staminal column

and the anthers have not yet commenced to burst. Soon after daybreak, the stigmas still remain flush with the opening of the column. After this the turgidity of the filaments falls off and the burst anthers bend back towards the column. Simultaneously the styles elongate and carry the stigmas into the air beyond the opening of the column and at this stage pollen grains are rarely seen on the stigmas. Sometimes, however, the styles bend outwards and carry the stigmas on to the pollen, then bringing about self-pollination. Frequently no pollen is seen on the stigmas when the flowers begin to close about midday. If closed flowers, however, are opened carefully it is found that they are always well pollinated. Self-pollination is effected almost entirely by the closing of the corolla. The limb of the petal is thin, the claw very thick. The corolla closes by the falling towards the centre and twisting of the thin limbs. This brings the corolla in contact with the burst anthers and the completion of the closing of the flowers covers the stigmas with pollen."

They stated that crossing was possible from the time the styles began to carry the stigmas beyond the opening of the column to the closing of the flower. Self-pollination, however, may also occur during this period.

From their experiences Howard and Howard (33) found that the flowers of this species did not set seed under a bag in the ordinary way unless artificially self-pollinated. This was apparently because the flowers did not close normally when enclosed in the bag. They reported that the thin limbs of the petals did not fall together and twist in the usual manner, possibly on account of the even humidity of the air both outside and within the closing corolla.

Cytogenetics of Hibiscus cannabinus

From the small amount of existing information, there appears to be considerable disagreement regarding the chromosome complement of Hibiscus cannabinus. Some authors report that this species is a diploid, whereas others have found it to be a tetraploid. Ford (18) offers the explanation that possibly H. cannabinus may be composed of diploid and tetraploid races as is its close relative H. esculentus L., reported by Skovsted (57). The former found the chromosome complement of H. cannabinus to be 2n = 72, whereas the latter and Breslavetz, et al. (6) found it to be 2n = 36.

In a study, by Narasinga Rao (49), of the chromosome complements of Hibiscus cannabinus and H. sabdariffa, a number of somatic metaphase plates were counted in the two species, and in each case the number of chromosomes was found to be 2n = 72. He stated that a preliminary examination of chromosome complements in the two species revealed certain morphological differences in that the chromosomes were thicker and longer in H. sabdariffa than those in H. cannabinus; and in the former species the number of U- and V-shaped chromosomes was greater, whereas in the latter the number of rodlike chromosomes was larger.

Medvedeva (43) reported that all the crosses between the varieties and geographical races of Hibiscus cannabinus belong to the type of "congruent" crosses and are successful. From his study he obtained the following data:

Plant material	2n =
H. cannabinus	
var. purpureus	36
var. ruber	36
var. viridis	36
var. vulgaris	36
var. simplex	36
H. sabdariffa	
var. altissima	72

Badenhuizen (2), by treating the apical meristems of young diploid (2n = 36) Hibiscus cannabinus plants with colchicine solution or with morpholine-colchicine emulsion, was able to obtain tetraploid (4n = 72) plants of this species. He observed that the diploid and tetraploid plants resembled each other closely, but the latter showed a high percentage of pollen sterility and had broader and thicker leaves. He noted that the offspring of diploid and tetraploid plants possessed about the same rate of growth and advanced the theory that fibers of induced tetraploids may have a greater length and diameter than those of the diploids from which they have been obtained.

ANATOMICAL PORTION OF PLANT USED FOR FIBER

The fiber obtained from the stems of Hibiscus cannabinus varies from 5 to 10 feet in length (12). Each filamentous strand of fiber is composed of cells, their ends overlapping, which vary considerably in size but average about 5 millimeters long and 20 microns wide. These cells form collectively the principal part of the bast layer which gives strength and flexibility to the stem. This layer is located just under the bark of the plant and immediately outside the central woody cylinder.

ENVIRONMENTAL AND SOIL REQUIREMENTS

According to Caldwell (8), Kenaf is capable of adapting itself to a large variety of climatic and soil conditions, although, as it is sensitive to frost, it is best grown in tropical or subtropical locations. Early maturing strains (3) have been selected so that the plant can be grown under the conditions existing in Central Asia. Wasserman (64) reports that extensive experiments have proved that the northern limit of this plant is 45°

north latitude. Hautefeuille (25) and van Gorkom (20 vol. 3, pp. 492-499) report that Hibiscus cannabinus can be grown up to about 1,600 feet above sea level. Biswas (4) and Carter (9) state that the plant is not uncommon in the lower Himalayas up to an elevation of about 3,000 feet. Watt (65) reports the plant at elevations of 3,000 feet above sea level in the lower Himalayas but also states that others have reported its growth at elevations of as much as 7,000 feet. According to van Gorkom (20) and Zegers Ryser (69), the area of this plant under cultivation should be free or protected from strong winds, since the plants grow so fast and get so tall that they cannot stand much wind. Extremely heavy rains are also detrimental in that they beat down the plants, and difficulty in harvesting results.

Horst (31), in discussing the climatic requirements of Hibiscus cannabinus, states that a period of rain for at least 4 to 5 months during the year is essential, and immediately thereafter an adequate dry period is needed to "disinfect the soil and bleach the fiber." Prior to 1917-18, he found that this plant was grown in the Netherlands Indies as a "second" crop after rice at the close of the rainy season, with the result that very low yields of fiber were obtained. After experimentation, it was found that the plant, for fiber production, had to be planted at the beginning of, and grown during, the rainy season.

According to Howard and Howard (33), the most important condition for the successful cultivation of this crop is a well-drained and well-cultivated soil. Waterlogged soils appear to be particularly detrimental, since these authors observed that in such soils the plants remained stunted and usually died before producing flowers and seeds. They pointed out that lack of aeration of the soil has an ill effect similar to that caused by waterlogging. This appeared to them to be a good explanation of the fact that in certain sections of India the plants are grown as a border crop on the edges of the fields, where the soil is slightly raised and better drained than in the rest of the field. Except for these two points, they state, cultivation is simple, and the best results are obtained when the crop is sown at the beginning of the rainy season.

Michotte (44) states that kenaf requires a certain amount of rainfall, but in swampy and wet soils good drainage should be provided. He noted that the fibers produced from plants growing on comparatively dry soils were 25 to 50 percent stronger than those from plants growing on wet soils. Michotte remarks that warm dry climates offer better possibilities for the cultivation of Hibiscus cannabinus, since too much rainfall is, in general, particularly injurious to this plant. According to him, it requires much less rainfall than jute, and in dry seasons it produces larger yields of fiber than in wet seasons. Ivanova (36) reports that larger yields of superior fiber can be obtained, in Russia, by irrigation. By applying irrigation water to the plants, the cellulose, lignin, fat, and resin content of the fiber increased with an accompanying decrease in ash and moisture content. El Kilany (17) states that this plant is not so sensitive to soil alkalinity and can stand more drought than jute. It also surpasses jute, in his opinion, in being able to grow on

poor soils. Zegers Ryser (69) and van Gorkom (20) both advise against the use of light sandy soils for the growing of Kenaf, but the soil should be fertile and porous. The former author states that plants growing on poor soils bloom ahead of time, are short, and consequently give low yields of fiber. Jong (39), after growing Kenaf on soils that varied from loams to black soils, recommends a good sandy-loam soil for this plant. Dekker (11) recommends a fertile, not too acid, and well-drained soil with a considerable quantity of humus present. Watt (66) states that rocky and laterite soils in India, which are not suitable for jute, are well adapted for the cultivation of Kenaf. He agrees that it grows best on alluvial soils and also states that it does very well on medium black soils.

Horst (31) lists two main soil requirements for the successful cultivation of Hibiscus cannabinus: (1) The texture should be "mixed" or "half heavy" (sandy loam) with (2) a water table that remains 1.5 to 2 meters 2/ below the surface. He states that the soil should not contain too much loam, for then it is too hard to work in the dry season and remains wet too long in the rainy season, and, furthermore, the soil must not be sandy, for in that case it dries out too rapidly and is difficult to irrigate.

In summarizing the environmental and soil requirements of this plant, the general opinion appears to be that any frost-free locality that is not subject to strong winds and has an adequate rainfall over a 4 to 5 months' period is suitable for Hibiscus cannabinus. A well-drained, sandy-loam soil, about neutral in reaction, with a considerable quantity of organic matter, appears to be the best soil type for this plant.

CULTURAL REQUIREMENTS

From a scientific standpoint, the cultural requirements of Hibiscus cannabinus have not been determined extensively. With a few exceptions, the following statements are based primarily on observations by various individuals and are not substantiated by scientific experimentation. According to Dekker (11), the culture of Kenaf is about the same as that of roselle, and therefore the cultural requirements of one species might be applied to the other, except for the fact that roselle flowers according to season (is subject to length of day); that is, regardless of the time of planting throughout the growing season, all plants bloom at the same time. On the other hand, H. cannabinus does not react in this manner and is not greatly influenced by varying photoperiods (5).

Preparation of the seedbed

Howard and Howard (33), Zegers Ryser (69), and van Gorkom (20) have all observed that Kenaf responds well to good soil preparation. The soil should be deeply and thoroughly worked in order to provide a good medium for seed germination and to insure proper soil aeration for the seedlings that follow. Hard

2/ One meter equals about 3.3 feet.

layers of soil close to the surface are to be guarded against, since this condition retards growth and consequently reduces yields, according to Zegers Ryser and van Gorkom. Good soil preparation and cultivation are essential to the development of this plant because of its characteristic type of root system. The work of Howard and Howard (34), shows that the taproot of Hibiscus cannabinus grows to comparatively great depths, and the development of laterals is not concentrated near the soil surface.

Horst (32), in a study of the root development of Hibiscus cannabinus, found, upon examination of 400 plants, the average length of the root system of this species to be about 18 centimeters, and he recommends that the soil should be plowed to a depth of at least 20 centimeters (8 inches). He states that the soil is best prepared if first plowed 15 centimeters deep and then harrowed or cultivated 10 centimeters more, rather than if plowed at first down to a depth of 20 centimeters.

Dekker (11) states that too much attention cannot be given to the preparation of the seedbed, since every effort should be made to ensure a uniform germination of the seed and particularly an even stand of plants, so that there will be uniformity in the size of the stalks at harvesttime.

Fertilization

A considerable quantity of humus is important to good production, according to Dekker, and this can be supplied either in the form of manure or green-manure crops, both of which greatly stimulate the growth of Hibiscus cannabinus. He suggests the use of Crotalaria anagyroides, C. usaramoensis, C. juncea, and Mimosa invisa. If M. invisa is used, care should be taken to see that it is plowed under after about 40 days of growth. If its seed are allowed to mature, it then becomes a serious pest. From preliminary experiments, Dekker increased yields of Kenaf, in Java, up to 50 percent by the use of M. invisa supplemented with ammonium sulfate at the rate of 1,300 pounds per hectare (about 2.5 acres).

Horst (31) advises: "Plant nutrients should be at hand in abundance and in a form to be readily assimilated by the plants.... To fulfill these conditions, a generous application of humus is necessary. This, as well as the other necessary nutrients, can be most easily applied to the ground by green manuring." He states that immediately after the fiber plants have been mowed a green-manure crop can be planted, without plowing, among the Hibiscus cannabinus stubble. In Java, sufficient moisture remains in the soil for a green-manure crop to grow in the period following harvest of Kenaf. There, after 3 to 3.5 months of growth, the recommended green-manure crop, Crotalaria anagyroides, is turned under. In order to reduce the danger of diseases in the soil, Horst (31) further advises that a rotation of crops should be established, using such food crops as rice, corn, or sorghum following the fiber crop. He recommends dividing the available land into two or more sections (see following examples, which are applicable in Java,) and alternating the crops in these sections so that all the land area will not be in one crop at one time.

Field A	Field B
Oct.-Feb. incl.,-H. cannabinus	Oct.-Feb.,- Food crops
Mar.-Apr.,- Green manure	Mar.-Apr., - Green manure
May-June, - Plowing and turning the soil	May-June, - Plowing and turning the soil
July-Aug.,- Soil fallow, ground lies undisturbed during dry season	July-Aug.,- Soil fallow, ground lies undisturbed during dry season
Sept.- Soil worked	Sept.- Soil worked
Oct.-Feb.,- Food crops	Oct.-Feb.,- H. cannabinus

Planting distances

El Kilany (17) states that, in Egypt, Hibiscus cannabinus can be sown broadcast, drilled, or seeded on ridges, but he recommends drilling or sowing on ridges. He found sowing on ridges the more common method, which is easily followed by the Egyptian farmers. The seed is sown in holes 20 centimeters (8 inches) apart, 6 seeds per hole, in ridges 54 centimeters (21 inches) apart. Fifteen kilograms (33 pounds) are required per acre. After the seedlings have reached sufficient size, they are thinned to 2 or 3 per hill, according to the fertility of the soil. Walters (63) says H. cannabinus, in Rhodesia, is sown in drills 9 inches apart at the rate of 30 pounds per acre.

Horst (32), in Java, states that the usual planting distance in average soil is 30 x 7 centimeters (12 x 2.8 inches), making a total of about 476,190 plants per hectare (about 192,700 plants per acre). Van Gorkom (20) recommends a planting distance of 15 x 15 or 15 x 12.5 centimeters (approximately 6 x 6 or 6 x 5 inches) on dry or upland soils, but on lowland or rice fields the plants should be spaced at a distance of 12.5 x 12.5 or 12.5 x 10 centimeters (approximately 5 x 5 or 5 x 4 inches). Michotte (44) also recommends a spacing of 15 x 15 centimeters (6 x 6 inches) on dry soils and a spacing of 12 x 12 or 10 x 10 centimeters (4.7 x 4.7 or 4 x 4 inches) on wet soils. Van Gorkom, however, states that a spacing of 10 x 10 centimeters (4 x 4 inches) is too close. In his opinion, seeds of Hibiscus cannabinus lose their germinating ability rapidly, and he recommends that 3 seeds be placed in each hole and that the less vigorous plants be removed as soon as the plants are 10 to 15 centimeters (4 to 6 inches) high.

Dekker's recommendations (11) as to the planting distance for Kenaf, under the conditions in Java, are in pretty close agreement with those of above-mentioned authors in that he recommends spacing the seed 15 x 15 or 20 x 20 centimeters (6 x 6 or 8 x 8 inches) on the square, which requires from 15 to 20 kilograms of seed per hectare (13 to 18 pounds per acre). The seed are planted 1 to 1.5 centimeters (0.4 to 0.6 inch) deep, 2 or 3 to a hill, and the less vigorous plants are then later removed.

Zegers Ryser (69) says that the planting distance varies from 12.5 to 15 centimeters (5 to 6 inches) on a square, depending upon soil fertility. Two seeds are dropped in each hole, and if germination is good the planting is thinned to one plant per hole. He states that broadcasting at the rate of about

38 pounds per acre gives equally good results; but, since a uniform stand of plants is particularly desirable, this method should be employed with caution.

The planting-rate recommendations of the various authors have been tabulated (see table 1) for easy comparison.

Table 1.-Recommended planting distances for the production of Kenaf fiber

Author	Country	Distance Between Plants	Distance Between Rows	Seed Per Acre
		Inches	Inches	Pounds
Dekker	Java	6-8	6-8	13-18
Horst	Java	2.75	12	-
El Kilany	Egypt	7.9	21	33
Michotte	-	dry soils 6	6	-
		wet soils 4-4.7	4-4.7	-
Zegers Ryser	Java	5-6	5-6	-
van Gorkom	Java	dry soils 5-6	6	-
		wet soils 4-5	5	-
Walters	Rhodesia	(drilled)	9	30

For seed production, Dekker (11) states that the plants should be spaced 75 to 100 centimeters (30 to 40 inches) apart on a square which requires from 1 to 2 kilograms (0.9 to 1.8 pounds per acre) of seed per hectare. Dounin (13) found the best planting depth to be 0.5 centimeter (about 0.2 inch).

Cultivation

Hibiscus cannabinus is very sensitive to changes in soil aeration, according to Howard and Howard (33). In environments where the roots do not get sufficient aeration the plants are stunted and usually die before forming flowers and seed. The leaves are small and narrow, and root development is exceedingly poor. They state that this is particularly noticeable at the end of the rainy season, when crops that have done well up to this time often show signs of wilting. If the soil is not cultivated when these symptoms appear, the plants will die. On the other hand, the plants will revive immediately if the soil is properly aerated through cultivation practices. When grown under favorable conditions, and especially when grown on high-lying, freely draining soils that have been cultivated from time to time, the crop is tall and vigorous, and large fields of good fiber are obtained. In speaking of its cultivation in India, Howard and Howard state: "If the cultivation of this crop is ever taken up in the plains on a large scale for fibre purposes, waterlogging must be prevented and the necessity of frequent cultivation, especially after the monsoon, must be insisted upon."

In Java, according to Dekker (11) and van Gorkom (20), if Kenaf is planted on sugarcane land (rather poorly drained), the fields are divided into strips 1 meter wide with drainage ditches on each side 0.25 meter wide and 0.25 meter deep to provide adequate drainage.

Horst (31) states that weeding is one of the most important operations in the culture of Hibiscus cannabinus. He advises that weeding be begun as early as 2 or 3 weeks after planting; otherwise there is danger that the weeds will easily choke out the crop. He states that the best practice would be to weed at the end of 2 weeks and then twice afterward with intervals of a week between. After a month's time, the plants will have reached a height of 0.75 meter. Following this, difficulty is experienced in going through the field with a team or machine but, due to the shading effect of the plants after they have reached this height, cultivation for weed control is hardly necessary.

Methods and time of harvesting

Three methods of harvesting have been reported. The plants are reaped with a mower, cut with a sharp blade or knife, or pulled up by the roots. Roxburgh (55) states that in the harvesting process the plants are either cut close to the ground or pulled up by the roots, since the lower part of the stem contains the best fiber. He also states that full-grown plants which have ripened their seed furnish stronger fiber than plants which are cut while in flower, though the fibers of the species are more remarkable for their fineness than for strength.

Caldwell (8) says that Hibiscus cannabinus plants grow rapidly and are ready for harvesting about 3 months after sowing. In his opinion, cutting the plants is preferable to pulling, for the production of good-quality fiber, though the yield in the former case is slightly lower. This slightly reduced yield, however, is compensated for by the higher price obtained, the product of the cut stems being free from the coarse fiber at the base of the mature plant

According to certain writers (11 and 31), higher yields of fiber are obtained if the plants are allowed to reach maturity than if they are cut and retted at some earlier stage. The highest quality fiber is obtained, however, if the plants are harvested during the flowering period. Watt (65) reports that a line made of fiber obtained from plants when in blossom and retted immediately broke when dry with a weight of 115 pounds, and when wet it broke with a weight of 133 pounds. On the other hand, a line made of fiber obtained from plants that were cut when the seed was ripe broke, when dry, with a weight of 110 pounds and, when wet, at 118 pounds. In conclusion he states: "According to these experiments the Ambári fibre deteriorates by the plants being allowed to grow beyond the flowering season."

In a Bulletin of the Imperial Institute (21), four samples of Hibiscus cannabinus are reported to have been received from the Rustam Experimental Farm

in Iraq. These samples were obtained from plants that were harvested at different times, and the fiber was examined and analyzed in an effort to determine the proper stage of growth at which plants should be harvested to obtain the highest quality fiber. The fiber samples were described as follows:

(a) First cutting (before flowering) - "Lustrous fibre, generally silver-grey to pale yellowish-brown in colour, but rather browner at the butts. The fibre had been on the whole fairly well prepared, but was somewhat harsh, especially at the butt ends, which were imperfectly cleaned and separated. A few rather hard ribbons were present. The sample was dusty. The length varied from 6 ft. to 8 1/2 ft., being mostly about 7 ft. The strength was fairly good on the whole, but in parts the fibre was very brittle."

(b) Second cutting (beginning of flowering) - "Lustrous, fine fibre, mostly pale cream to pale yellowish-brown in colour. The fibre had been well prepared and was on the whole cleaner and softer than [a]; the butts had been rather better cleaned and separated. Like [a], however, the sample contained a rather large amount of dust. The length varied from 7 1/2 ft. to 10 ft., being mostly about 8 ft. Some of the fibre possessed good strength, but much of it was weak and brittle."

(c) Third cutting (at flowering time) - "Very lustrous fibre, mostly pale cream to pale yellowish-brown in colour. In preparation and appearance the fibre was generally similar to [b] and the butts had been fairly well cleaned. The length varied from 6 to 10 ft., being mostly about 8 ft. The strength of the fibre was variable (some portions being weak and brittle) but it was on the whole better than that of [b]."

(d) Fourth cutting (at period of seed formation) - "Lustrous fibre, cream to pale brown in colour, and slightly inferior in preparation to [a]. The sample was rather dusty. The length varied from 6 to 7 1/2 ft.... The strength was very irregular, much of the fibre being weak."

The samples, excluding the butts, were chemically examined, and the results are shown in table 2, to which are added, for comparison, the corresponding figures recorded for Bimlipatam jute (<u>Hibiscus cannabinus</u>) from India, which had previously been examined by the Institute.

The conclusion was (<u>22</u>) that samples (b) and (c) "contained rather more cellulose than the others, indicating that the best time for harvesting the plant may be during the flowering period; these two samples also suffered smaller losses on hydrolysis than the others, but the hydrolysis figures are all comparable with those obtained for samples of <u>Hibiscus cannabinus</u> of good quality previously examined at the Institute."

Table 2.-Chemical analysis of Hibiscus cannabinus fiber harvested at different growth stages

Item	Present Samples				Bimlipatam
	a	b	c	d	Jute
	Percent	Percent	Percent	Percent	Percent
Moisture	10.1	13.1	13.7	13.0	12.5
Expressed on the moisture-free fiber:					
Ash	1.9	2.2	1.1	1.0	1.3
a hydrolysis, loss	10.7	8.4	7.5	10.2	11.8
b hydrolysis, loss	13.2	12.4	11.4	14.6	15.1
Water-washing, loss	1.3	0.9	0.1	1.5	-
Cellulose	73.7	75.8	76.5	75.0	75.4

The samples were submitted to merchants in London (Messrs. Wigglesworth & Co., Ltd.) who furnished the following data: With Bimlipatam jute [Hibiscus cannabinus] and Calcutta jute obtainable at 21 pounds (about $102.10) for the former and 22 pounds 10 shillings ($109.40) for the latter, the value of this quality would be 18 pounds per ton for (a), 20 pounds ($97.24) per ton for (b), 21 pounds ($102.10) per ton for (c), and 19 pounds ($92.38) per ton for (d). Thus the fiber of the quality of samples a, b, c, and d would be salable in London at fair prices, and that the most valuable are b and c, cut during the flowering period.

El Kilany (17) says that the plants in Egypt are cut either at full flowering or after capsule maturity; however, fiber from the first stage, he states, is more lustrous and softer.

Zegers Ryser (69) and van Gorkom (20) both state that after 2.5 months of growth the flowers begin to open and after a period of 90 to 100 days the plants are ready to harvest. The former recommends that for best quality fiber, the plants should be cut when the stalks, just above the crown or ground level, become woody and when the lowermost seed capsules have reached maturity and turned brown. He states that, after the plants are pulled up or cut off at the ground level, the leaves and seed capsules are removed before the stalks are roughly sorted and tied in bundles. In removing seed capsules and leaves, he advises, one must work from the base of the stem upward; otherwise, if worked from the terminal end toward the base, the bast is injured.

Zegers Ryser (69) further states that, for seed, the crop should grow 4 to 4.5 months or from 1 to 1.5 months longer than if grown for fiber. According to him, the harvesting of seed is rather difficult, since the capsules are covered with fine hairs which seriously irritate the skin. In Java, the seed is cleaned, after it is well dried, by beating it over a screen with a stick of wood or a stone. The hairs drop through the screen leaving the clean seed

behind. A single plant sometimes yields as much as 1,000 seeds but the viability of seeds decreases rapidly and after 8 months are generally useless for planting.

Poptsov (<u>54</u>) found that Kenaf seed harvested before maturity require 2 to 5 months, depending upon degree of ripeness, to reach full maturity, and the best seed for sowing are those ripened on the plants before harvesting. He found that seed, even under the most favorable conditions of storage, lose their viability quickly. From his experiments, he reports that the optimum temperature for the germination is a little below 35° C. (95° F.); the minimum is above 8° C. (46.4 F.), and maximum is about 40° C. (104° F.). He states that air-dried seed lose their viability if subjected to 80° C. (176° F.) in dry air or 70° C. (158° F.) in moist air. Seed moistened until they contained 40 percent hygroscopic moisture were still more subject to injury from high temperature.

Dounin (<u>13</u>), on the other hand, in a study of the effect of various factors on germination of <u>Hibiscus</u> <u>cannabinus</u> seeds, found the minimum germination temperature to be about 6° C. (42.8° F.); optimum 22 to 25° C. (71.6 to 77° F.), and maximum 37 to 42° C. (98.6 to 107.6° F.). He found that the seeds are very sensitive to changes in acidity, with a pH of 6.5 to 7 being optimum. Diffuse light, in his experiments, had no effect on germination.

Dounin, et al. (<u>14</u>) state that <u>Hibiscus</u> <u>cannabinus</u> seeds germinate, as a rule, very quickly, usually by the end of 4 days. They found the optimum degree of humidity needed for seed germination on filter paper is equal to 230 to 300 percent of the moisture capacity of the paper. They also observed that treatment with certain concentrations of zinc had a beneficial effect on seed germination.

RETTING

The length of the retting period varies from 5 to 22 days (<u>44</u>). This variation might well be expected when one takes into consideration the numerous factors that are said to influence the degree and length of time that a given sample of material should be retted. From an examination of the existing data relating to the retting of <u>Hibiscus</u> <u>cannabinus</u>, one should expect to find considerable variation in recommendations as to the best retting procedure because of greatly divergent environmental conditions that exist in the various locations where the plants are grown, the differing stages of maturity of the plants at the time of harvesting, the different kinds and temperatures of the retting water used, and the many other differing interrelationships that were not considered or controlled.

Caldwell (<u>8</u>) states: "Steeping [retting] occupies from five to ten days, and as the stems are being removed from the water at the end of this process the fibre is usually stripped off by hand, being subsequently dried and threshed or beaten with wooden mallets to soften the fibres and assist in separating the strands from each other and from the plant tissue in which they are embedded."

Pole-Evans (52), in South Africa, says the plants are tied in bundles and then retted in running water for 10 days or more, running water being better than stagnant. The bundles are first placed in an upright position in the water, he continues, so that the thicker root ends may be thoroughly soaked, when, after about 2 days, the bundles are laid down horizontally and entirely immersed. As soon as the retting has advanced sufficiently, the fiber is stripped off by hand and cleaned by dashing it against the surface of the water or a board erected for the purpose. At the botanical laboratories in Pretoria, with the temperature of the water varying from 18 to 26° C. (64.4 to 78.8° F.), the time required for retting was found to vary from 10 to 14 days. Van Gorkom (20) also recommends retting the lower and older portions of the stems first, but for a period of about 4 days, after which time the plants are entirely submerged.

Horst (31) states that, if the stalks are retted immediately after harvesting, the time required is 21 days and the fibers are still not absolutely slime-free; but, if the stalks are previously dried, they can be retted in 15 days and a clean fiber is obtained. Although Dekker (11) observed that the fiber could not be extracted by machine without serious damage, Wassermann (64) reports that in Russia a decorticator has been designed whereby the fibers of Kenaf stems can be extracted and subsequently spun and fabricated with good results.

Experiments, reported on by Dekker (11), served to show that retting should be done in slowly running water so that the decomposition products of the retting process will be removed from the retting basin. The retting residues are heavier than water and can be drained off at the bottom of the tank. He suggests a method of constructing retting basins by throwing up dikes around an area 10 x 25 meters (33 x 82.5 feet) and allowing the water to run in and fill up this area. A basin this size, according to him, will hold the stalks produced from one hectare (2.5 acres). If the water intake is regulated so that it requires about 2 days to fill the basin, the flow will be sufficient to change the water 4 times during the 8-day retting period. Under the conditions prevailing in Java and with the use of such a retting basin as described above, the length of the retting period was about 8 days. He cautions that the stalks being retted should be watched closely to ensure that they are not overretted, since this greatly reduces the quality and value of the fiber. He also suggests that a series of small dams can be constructed in a nearby creek to provide ponds that can be used as retting tanks very satisfactorily. He states that the lower ends of the stalks require a longer retting period than the upper ends and suggests, to simplify the retting process, that the stems can be cut before the basal portions have approached maturity. This procedure, however, reduces the ultimate yield of fiber and a better method is to cut the stalks in two pieces and ret each separately. After retting, he states, the bast is easily separated from the wood, and the fibers may then be washed and dried in the sun.

Zegers Ryser (69) described the retting process as he knew it in Java. The stalks could be left in the field for 1 or 2 days after they were cut, and, if the plants were pulled up in harvesting, a good procedure was to cut off the

roots, because the fibers obtained from them were discolored. Retting could be done equally well, according to him, in flowing or still water. If the latter was used, it was changed every day or at least every other day. He states that the retting process is generally concluded in 8 to 14 days, but this is dependent upon the temperature of the water as well as the stage of maturity of the plants when harvested, the composition of the retting water, and other related factors. When the stalks have been retted sufficiently, the bundles are broken open by hand and the bast, which is loosened at the lower end of the stalk and pushed out over its entire length, is separated from the stalks one by one. The mass of unpurified fiber is washed in clean water and then dried in the sun. In favorable weather, the fiber is dry in about 0.5 hour and can then be straightened out for packing. He states that methods for preparing the fiber, other than retting, have not given good results and therefore, when planting Hibiscus cannabinus for fiber purposes, one must keep in mind that an available and adequate water supply should be on hand at harvesttime.

In summarizing these statements on the retting of Hibiscus cannabinus, one can say that some differential retting procedure should be followed, in order that the upper portion of the stem is not overretted or the lower portion underretted. Generally speaking, the retting time required is about 6 to 10 days, depending upon existing environmental conditions and other related factors associated with retting. That overretting reduces the quality of the fiber is generally conceded.

Table 3.-Average yields per acre of Hibiscus cannabinus fiber, according to various authors

Author	Country	Yield per Acre
		Pounds
Michotte (44)	India	1,561-6,245
Michotte (44)	Egypt	2,719
Michotte (44)	Senegal	1,561
Pole-Evans (52)	India	2,000-4,000
(41)	Nigeria	1,174
Walters (66)	Rhodesia	1,296
Horst (32)	Java	1,981
Dekker (11)	Java	1,000
El Kilany (17)	Egypt	2,000

The yield of fiber from Hibiscus cannabinus (see table 3), as one would expect, is greatly divergent, depending upon the environment in which the crop is grown, the cultural methods employed, the conditions under which the stalks are retted, and other related factors. Van Gorkom (20) and Zegers Ryser (69) state, that on the average, the green stems contain about 1.5 to 2 percent fiber, whereas El Kilany (17) states that the ratio of fiber yield to green-crop weight is from 7 to 10 percent. Michotte (44) reports that in Central Asia the plants yield between 11 and 22 percent fiber of the dry weight of their stems.

Horst (31), in a study to determine the percentage of fiber in plants harvested at different growth stages and also the percentage of fiber in thick as compared with thin stems, found that in the case of plants which were harvested too green (97 days after planting) and which "still had all their leaves and were very full of sap," a yield of 1.66 to 2 percent of fiber was obtained. When the plants were harvested at seed maturity, however, the yield of fiber amounted to 6.44 percent. He noted that the yield of high-quality fiber was between these two figures, probably at 4 or 4.5 percent. Horst also found that the percentage of fiber from air-dried, "thick" stalks was 18.5, whereas the percentage of air-dried "slender" stalks was 33.9 percent. These figures indicate that larger yields of fiber per area of land could be obtained if the plant population were dense enough to promote the growth of tall, slender stems rather than if the population of plants were smaller with thick stems.

Michotte (44) reports the yield in India as varying from 1,750 to 7,000 kilograms per hectare (1,561 to 6,245 pounds per acre); in Egypt, 3,500 kilograms per hectare (3,123 pounds per acre); and in Senegal from 1,750 to 2,000 kilograms per hectare (1,561 to 1,784 pounds per acre). Pole-Evans (52) reports the yield in India as being from 1 to 2 tons per acre. In Nigeria (41), rich soils were reported to give a yield of 1,316 kilograms per hectare (1,174 pounds per acre). Walters (63), in Rhodesia, reports that seed sown in drills 9 inches apart at the rate of 30 pounds per acre yielded 20,640 pounds of green cane. The cane was dried down to 12,960 pounds before retting, and a yield of 10 percent of the dry weight of the stalks or 1,296 pounds of fiber, was obtained.

In a study of Hibiscus cannabinus fiber, Horst (31) found in a particular green variety, with which he was working, that the weight of the bark, which consisted of from 30 to 50 percent of fiber, constituted about a third of the weight of the stalk, or the fiber content of the dried stalks varied from approximately 10 to 17 percent. He stated (32) that, with the usual planting distance in average soil of 30 x 7 centimeters (12 x 2.8 inches), a population of 476,190 plants per hectare (192,700 plants per acre) is obtained, which yield in the neighborhood of 2,220 kilograms of fiber per hectare (1,981 pounds per acre). Of the many plants that he sampled, he found that each plant, on the average, contained 10 grams of fiber. He stated that, consequently, with 10 grams of fiber per plant, half of this plant population (476,190) should be enough to give the yield of fiber that is commonly obtained (2,220 kilograms). From this study, he concluded that, by increasing the planting distance, yields of at least 4,000 kilograms of fiber per hectare (3,569 pounds per acre) could be obtained.

In a study of the disposition of fibers in the stem of Hibiscus cannabinus, Horst (32), by cutting the stems into thirds in one experiment and into quarters in another, found that the lower part of the stem had the greatest amount of fiber, but the middle part had the highest percentage. He advanced the suggestion that the amount of fiber increases in proportion to the square of the

relative increase in length of the stem; therefore, by increasing the length of the crop, a considerable increase in the yield of fiber can be obtained.

Dekker (11) reports that, in Java, under favorable conditions and by fertilizing with ammonium sulfate at the rate of 6 quintals per hectare (535 pounds per acre), a yield of about 10 quintals of fiber per hectare (892 pounds per acre) is obtained. He found in preliminary tests that green-manuring with *Mimosa invisa* increased yields 50 percent. Badenhuizen (2), in Java, found that the yield of fiber from *Hibiscus cannabinus* was generally less than the fiber yields of *H. sabdariffa* (roselle). Zegers Ryser (69) states that yields of *H. cannabinus* are very divergent according to the soil in which the plants are grown and the climatic conditions prevailing during the growing season. The highest yield of fiber obtained in Java, according to him, is 20 piculs per bouw (1,556 pounds per acre), with 5 piculs per bouw (389 pounds per acre) more nearly the average production, but 10 to 15 piculs per bouw (777 to 1,165 pounds per acre) can be obtained on very good soil.

El Kilany (17) reports that, in Egypt, various yields were obtained (see table 4).

Table 4.-Effect of planting method on yield of fiber from three selections of *Hibiscus cannabinus*

Selection No.	Mataana Experiment		Kom Ombo Experiment	
	On Ridges	Drilled after Plow	On Ridges	Drilled after Plow
	Pounds per acre	Pounds per acre	Pounds per acre	Pounds per acre
33	1,777	1,693	2,143	2,293
53	2,460	3,405	2,240	1,870
54	2,064	2,130	3,042	2,249

In a study to determine the production of *Hibiscus cannabinus* on various levels of soil fertility, he obtained the data presented in table 5.

Table 5.-Effect of soil fertility on fiber production of *Hibiscus cannabinus*, green-crop weight 1/ from seed sown on ridges

Locality	Soil Type	Selection Numbers		
		33	53	54
		Pounds per acre	Pounds per acre	Pounds per acre
Khorshid farm	alkaline	8,604	6,657	7,247
El-West farm	med. fertility	9,319	15,105	10,545
El-Hawaslia farm	good	25,395	21,437	29,515

1/ Ratio of fiber yield to green-crop weight is from 7 to 10 percent.

DISEASE AND INSECT PESTS

In Java, Muller and van Eek (47, 48) report that the diseases which attack Hibiscus cannabinus are foot rots, which generally result in the death of the plant; and stem and foliage diseases, which are of much less importance. Foot rots are caused by Pythium perniciosum Serbinow, Rhizoctonia solani Kuhn, Sclerotium rolfsii Sacc., and Phytophthora parasitica Dastur. The foot rot caused by the last-mentioned organism, according to these authors, is the most serious disease. This foot rot is described as a black basal rot, gradually merging into the sound tissue by way of an ill-defined water-soaked zone, and extending upward for a height of 30 to 35 centimeters (12 to 14 inches) or up to 1 meter (about 3.3 feet) above ground level. In both these respects, according to Muller and van Eek (48), the Phytophthora rot differs from those due to R. solani and S. rolfsii; the discolorations induced are sharply differentiated from the healthy areas, and the height attained by the decay does not exceed 5 centimeters (2 inches). Older lesions of P. parasitica harbor a rich secondary mycoflora, among which several species of Fusarium of the F. (solani var.) martii group predominate. These authors observed that occasionally in loose, sandy soils the roots may also be attacked by P. parasitica, which was further observed to cause local infections high up on the stem, resulting in unilateral wilting in contrast to the general dieback of the upper portions of the plant following invasion of the stem base or root system. They state that these local infections may proceed either from the lower leaves, which are frequently spattered with spores from the soil during rainy periods, or from contact with diseased plants in plantings where prompt eradication is not practiced. Muller and van Eek (48) have observed cases in which one diseased plant contaminated 5 to 12 adjacent healthy ones. H. cannabinus is relatively resistant to this disease, but prophylactic measures should include soil sanitation, especially on sites of previous infection and around inlets of irrigation water. These authors advise that arrangements should be made for the gradual infiltration of the irrigation water through trenches on to the plant beds so as to avoid immediate contact with a possible source of infection. Direct control should comprise the early decapitation of infected plants about 10 centimeters (3.9 inches) above the discolored stem area and the removal of the tops from the field. Freshly slaked lime should be applied to the remaining stumps, and after harvest these should be taken up and burned, and the soil should be disinfected with 0.1 percent "Terbolan" or "Cryptonal" solutions. Diseased stems should be picked out before the crop is retted to avoid contamination of the irrigation water. Unlike the other three agents of foot rot, according to Muller and van Eek (48), P. parasitica is not suppressed to any extent by antagonistic microorganisms.

Damage done by Pythium perniciosum is of minor importance in Java, according to Muller and van Eek (47). In inoculation experiments, these authors found that the microflora of unsterilized soils seriously hamper the parasitism of this fungus. For the control of this organism, they recommend 0.3 percent "ceresan" (5 liters per square meter or about .5 quart per square foot).

Rhizoctonia solani and Sclerotium rolfsii are reported by the same authors to be favored by dry weather with heavy dew formation, their development being restricted under normally humid conditions by the competition of other soil organisms. From their observations, direct control is seldom necessary in the case of these two foot rots, but sporadic outbreaks of R. solani may be combatted by spraying with 1.5 percent Bordeaux mixture or by a timely supply of irrigation water.

Hartley (24) states that Sclerotium rolfsii is of rather frequent occurrence on Kenaf in West Java. He observed this disease most frequently on plants whose early growth had been stunted by drought. Badly diseased plants appeared to be weakened in general, had small leaves, and ultimately wilted; the abscission of the lower leaves, which occurred in plants attacked by Bacterium solanacearum, did not take place. The lesions, which were dry and showed characteristic concentric red-brown and pale gray-brown zones, were sometimes found on the stems at considerable distances from the ground. Root-knot nematodes, Heterodera radiciola, were very abundant in one planting of Kenaf which he observed.

Stem and leaf diseases of Hibiscus cannabinus in Java, according to Muller and van Eek (48), are of no great economic importance. Phoma sabdariffae Sacc. and Cylindrocladium scoparium Morgan cause some foliar spotting, sometimes accompanied by top rot, and local necrotic lesions on the stem cortex are produced by Fusarium sarcochroum Sacc., F. Coeruleum Sacc., and Diplodia spp. They state that H. cannabinus appears to be less susceptible to attack by Fusaria than H. sabdariffa. The injuries caused by Fusaria attack may develop into unilateral cankers about 5 centimeters (2 inches) in length. After retting these dark blotches are visible on the fibers to which bark remnants adhere, thereby reducing the commercial value of the product.

Jochems and Maas (38) and Hartley (24) report that Hibiscus cannabinus is particularly subject to slime disease, Bacterium solanacearum. The first symptom of the disease is reported to be the assumption of a horizontal position by the petioles, followed by drooping of the leaves. As a rule, all the leaves of the plant droop at the same time. A further symptom observed by Jochems and Maas, generally noticeable the same day, is the curling of the leaves along the midribs, with the concave sides uppermost. The next day the leaves are tightly curled and hang straight down; soon afterward they are quite withered. Palm (51), in an experiment to test the resistance of H. cannabinus to the slime disease, found that the green and red varieties showed 62.4 and 26.5 percent resistance, respectively.

Letoff (42) reports that in Russia Kenaf exhibited a slight incidence (not over 3 percent) of a dwarf disease, which he believed to be caused by a virus, since no organism could be isolated from diseased plants. The condition was characterized by a stunting of the whole plant, which never reached more than one-fifth of the normal height. The leaves were "curled and crimped," had usually a reddish or yellowish tinge, and the apical ones assumed the form of

a rosette. He found that affected plants rarely blossomed. He observed on living leaves of Kenaf a species of Pleosphaerulina, which was previously referred to as P. suchumica Sacc. Other fungi observed by Letoff on this host were Oidiopsis hibisci and Ascochyta hibisci-cannabini. He states that the diseases of the greatest economic importance are bacteriosis of the leaves and stem tops, caused by unidentified species of Bacterium; sooty molds; the powdery mildew Leveillula (Oidiopsis) taurica; wilt (Fusarium vasinfectum); and root rot caused by an unidentified species of Fusarium and by Moniliopsis aderholdi.

Zaprometoff (68) also mentions Hibiscus cannabinus as being attacked by Moniliopsis aderholdi, which caused a root rot of young seedlings. In addition, he reports powdery mildew, Leveillula (Oidiopsis) taurica, as attacking H. cannabinus plants.

As to the seed-borne diseases of this plant, Dounin, et al. (14) report that there are most frequently found species of the genera: Alternaria Nees, Fusarium Link, Penicillium Lk., and Trichothecium Lk. Penicillium and Trichothecium were mostly found on the surface, whereas Alternaria and, particularly, Fusarium seemed to penetrate the seed tissues. A low germinating percentage of the seeds was correlated with the amount of disease present. They state a high degree of seed infection is connected with the fact that these seeds, as compared with those of other seed plants, have higher hygroscopic properties. These authors found that the limit of the degree of moisture that prevents developing microorganisms from seriously injuring the seeds is less than 13 percent. They state that, when drying seeds, the moisture content must be reduced during the first 24 hours to as low as 13 or 14 percent. When stored, they advise that the moisture content of the seeds should be controlled; in case it goes above the critical point of 13 percent, the seeds should be dried a second time.

In a study of the different modes of seed disinfection, Dounin et al. (14) report that the different methods are by no means equally efficient in lowering the degree of seed infection. After treating Kenaf seeds with formaldehyde solutions (0.15 and 0.30 percent) for 2 hours, they were entirely freed from living organisms, but at the same time their germinating power was considerably lowered. When treated with a 30-percent formaldehyde solution for 3 minutes, the degree of infection was lowered considerably less than by the former treatments but at the same time the germinating power was higher. Seeds were not successfully disinfected with various concentrations of copperas or by spraying with $CuSO_4$ and with $CuSO_4$ and CaO mixed. On the other hand, seeds treated with a KCN solution and with the gaseous HCN acid had their degree of infection lowered considerably, and both the germinating power and the development of the seedlings were stimulated.

Gitman and Boĭchenko (19) found that Hibiscus cannabinus seeds infected with Pseudomonas hibisci (= Phytomonas hibisci) became disinfected by a 5-minute treatment with a 0.1 percent solution of $HgCl_2$. They state that

artificially infected seeds had their germinability decreased by about 23 to 28 percent and plants developing from the seeds that germinated died before reaching the height of 15 centimeters (6 inches).

The only reference to insect pests of Hibiscus cannabinus which might cause some damage, especially to plantings grown for seed, is one made by Zegers Ryser (69). He states that Dysdercus cingulatus Fab. causes some loss by boring through the calyx and consuming the milky contents of the young seeds. No control for this insect is suggested except that the infested capsules should be removed and burned.

CHARACTERISTICS AND USES OF KENAF FIBER

According to van Gorkom (20), Dodge (12), Watt (66), and Horst (31), the fiber of Hibiscus cannabinus can be employed for the same purposes for which jute is used. Watt (65), Howard and Howard (33), Duthie and Fuller (15), Mollison (46), and Holmes-Smith (29), all state that this fiber is suitable for making coarse gunny cloth or sacking material, ropes and cordage of all kinds, fishing nets, well ropes, floor matting, etc. Duthie and Fuller (15) state that in some parts of India the dry stalks are split, tipped with a preparation of sulfur, and used as matches.

In considering its uses, Howard and Howard (33) said that Hibiscus cannabinus is, perhaps, the fiber plant most widely cultivated in India for local consumption in the form of string and cordage necessary for agricultural operations. Coarse sackcloth and canvas are made from it as well as fishing nets and paper. Watt (66), also working in India, states that the fiber is soft, white, and silky and is suitable for the coarser textile purposes to which jute is applied. The length of the extracted fiber varies from 5 to 10 feet, is somewhat stiff and brittle; and, though used as a substitute for hemp and jute, it is somewhat inferior to both. The fiber is bright and glossy but coarse and harsh.

Holmes-Smith (29) found the fiber to be slightly inferior to true hemp (Cannabis sativa L.) but superior to ordinary jute. He described the fiber as being pale brown or light straw-colored, somewhat harsher and coarser than jute, but superior in strength. A large amount of gum resin adheres to the fibers, he says, and this must be carefully removed if the fiber is to command a good price.

The ultimate fibers (single prosenchymatous cells of the bast), according to Biswas (4), vary from 1.5 to 4 millimeters 3/ in length and are 12 microns 4/ in width at the middle. The thickness of the wall is 4 microns and the lumen is 4 microns broad. Biswas further states that the roughness and coarseness of the fiber are due to the nature of the encrusting substance, lignin. He found that the lignin is not entirely spread over the fibers as it is in jute, which accounts for the difference in smoothness between the two fibers. In an experiment in

3/ One millimeter equals 0.0394 inch.

4/ One micron equals a millionth part of a meter (0.000039 inch).

which samples of Kenaf and Bengal-jute fibers were exposed for 2 hours to steam at 2 atmospheres followed by boiling in water for 3 hours and again steamed for 4 hours, the Kenaf fibers lost only 3.63 percent by weight, whereas the jute fibers lost 21.39 percent. He concluded that the Kenaf fibers were tougher and stronger than jute because of the nature of the lignification.

The commercially used fibers, according to von Höhnel (28), consist only of bast fibers that are up to 6 millimeters long, 14 to 21 microns broad (mostly 21 microns), and are either blunt, sometimes a very short lobe near the end, or else pointed, the walls at the ends being in both cases very strongly thickened. The lumen in one and the same fiber shows very great variation in diameter; in some parts it is broad, in other parts narrow, and still other parts disappears entirely. In cross-section, the fibers are seen to be closely united, and are either polygonal with sharp angles and straight sides or rounded polygonal with sharp angles and oval, the lumen in the first case being usually small, often a mere point; in the latter case large and oval. Cross sections examined in water show a broad, distinct outer lamella, but concentric rings are evident only in some of the angular forms and in those but indistinctly.

The data presented in table 6 summarize the work on the microscopical dimensions of Kenaf (*Hibiscus cannabinus*) bast cells in comparison with jute (*Corchorus capsularis*) cells.

Table 6.–Dimensions of Kenaf and jute bast cells as reported in the literature cited

Worker	Length of Bast Cells		Width of Bast Cells	
	Kenaf	Jute	Kenaf	Jute
	Millimeters	Millimeters	Microns	Microns
Hanausek (23)	6	2	14 - 16	24
von Höhnel (28)	5	2	21	22.5
Tobler (59)	1 - 5	1 - 4	20 - 25	15 - 25
Iterson (35)	2.7 - 3	2.1 - 2.4	18.94	17.5
Herzog (26)	4 - 12	0.8 - 4.1	20 - 41	10 - 32
Wiesner (67)	4 - 6	0.8 - 4.1	20 - 41	16 - 32
Vetillart (62)	5	2	21	22
Biswas (4)	1.5 - 4	-	12	-

Generally speaking, the fiber length of Kenaf is somewhat greater than that of genuine jute, and the fiber cells are generally somewhat longer, broader, and thicker walled than jute cells. There is considerable variation in the dimensions reported for each species, but Tobler (59) states that the variation in cell size within the species may be just as great as the variation between two species of plants. In a study of the comparative sizes of fibers from *Hibiscus* and *Corchorus*, he presents the following data:

	Hibiscus cannabinus	Corchorus capsularis (Jute)
Length of the fibers . . .	1.5 to 2.5 meters	1.5 to 4 meters
Length of individual cells	1 to 5 millimeters	1 to 4 millimeters
Width of individual cells.	20 to 25 microns	15 to 25 microns
Width of lumen	15 to 20 microns	5 to 7.5 microns
Thickness of cell wall . .	5 to 8 microns	7.5 to 10 microns

He states that there is a variation in the size of the lumen between Hibiscus cannabinus and jute and there is also a difference in the development of the cells. In Kenaf the cells are thinner walled and less pointed than in jute, and the ends of the cells are more curved.

In a study of Hibiscus fibers, Arno and Borschtschowa (1) found that two types of fibers exist in the stem of the plant; that is, primary and secondary. They state that the division of the outer bast cylinder (the primary fibers) from the inner cylinder (the secondary fibers) is easily distinguished, since there are no anastimosing fiber bundles between the two cylinders. The primary fibers distinguish themselves from the secondary fibers by being firmer and more tightly packed together, by being glossier, more flexible, and by exhibiting other differences when used in the manufacturing processes. According to these authors, the differences in the two types of fiber are due to the origin of the fibers. The primary fibers (the first bast cylinder) appear to originate from the terminal meristem, or the vegetative point, whereas the secondary fibers arise from the cambium. The percentage of primary and secondary fibers in a given plant varies according to its height, but, on the average, there are about 38 percent primary fiber and 65 percent secondary fiber. With a decrease in stem thickness, an increase in the percentage of primary fiber was noted; whereas, on the contrary, with an increase in stem thickness, the percentage of primary fiber decreased. As far as spinning qualities are concerned, Arno and Borschtschowa preferred the early ripening varieties of Hibiscus cannabinus, since they were found to contain 56 percent primary fiber and 44 percent secondary fiber. These workers concluded that in jute factories, owing to the fact that there is a difference in the fibers of any one plant, special readjustments would be necessary in the processing and spinning machinery of the factory in which Kenaf fiber was used.

Table 7.-Chemical analysis of Hibiscus cannabinus and Calcutta-jute fiber

Item	H. cannabinus	Calcutta jute
	Percent	Percent
Moisture	12.5	12.0
Ash	1.3	1.0
a hydrolysis, loss	11.8	9.2
b hydrolysis, loss	15.1	14.3
Acid purification loss	1.0	2.6
Cellulose	75.4	76.4
Length of staple	7 feet	8 feet

The fiber of Hibiscus cannabinus is somewhat less lignified than jute fiber, according to Horst (31) and Norman (50), but is similar in its content of water, ash, and cellulose as is shown in table 7, taken from the Bulletin of the Imperial Institute (21).

Norman (50) states that the better known commercial fibers fall into two well-defined groups, one having only small amounts of xylan in the fiber cellulose, and the other having considerably more. The so-called fine fibers, such as flax and ramie, according to Norman, fall into the first group, whereas the coarser fibers, such as jute and Hibiscus cannabinus fiber, must be included in the second. In his study, the results of which are presented in table 8, he found that H. cannabinus fiber contains only half as much lignin as true jute but otherwise is not very different.

Table 8.--Comparative chemical composition of Kenaf and jute fiber

Fiber	Cellulose	Lignin	Total Furfur-aldehyde	Cellulose Furfur-aldehyde	Xylan in Cellulose	Xylan as Percentage of Cellulose
	Percent	Percent	Percent	Percent	Percent	Percent
Kenaf (Hibiscus cannabinus)	76.6	5.9	11.3	8.9	13.8	18.0
Jute (Corchorus capsularis)	74.3	11.5	11.1	8.3	12.8	15.0

In a study of spinning tests made on the fiber of Hibiscus cannabinus and roselle (Hibiscus sabdariffa var. altissima), Spoon (58) states that the flexibility and divisibility of H. cannabinus fiber were more favorable than in the case of roselle, although these factors were less satisfactory than in the case of jute. In consequence of the lower flexibility there were many fibers sticking out, and the threads were very heavy. The breaking strength of threads made of a mixture of H. cannabinus and jute fiber was 5 to 10 percent lower than threads of similar size made entirely of jute. He concluded that threads spun with these two fibers, H. cannabinus and H. sabdariffa var. altissima, are more irregular, the strength varies, and difficulties are encountered in spinning them for thread and textile purposes. A finer thread can be spun with H. cannabinus fiber than with roselle fiber, but the breaking strength of both is 20 percent less than jute.

In a bulletin of the Royal Gardens of Kew (40), Hibiscus cannabinus fiber was reported to have a greater resistance than hemp, and that its specific gravity was less. The fiber can be chemically bleached without losing its value. "Thus, a cord of 8.25 millimeters [3.2 inches] diameter, woven with ... three threads ... requires 180 kilograms [397 pounds] to break it. A cord half an inch thick, manufactured at Moscow, did not break until the weight of 625 kilograms [1,378 pounds] was reached."

Michotte (44) reports the seed of Hibiscus cannabinus as having the following composition:

	Percent
Water	9.64
Mineral matter.	6.40
Oil	20.32
Nitrogenous material.	21.14
Saccharfriable material	15.66
Crude cellulose	12.90
Other material.	13.94

He states that 500 kilograms of seed per hectare (446 pounds per acre) can be produced, which can be utilized for cattle or poultry feed. A report from the Royal Gardens of Kew (41) also states that the seeds can be used as cattle food and a clear, limpid, drying oil can be extracted from them.

SUMMARY

Kenaf (Hibiscus cannabinus L.) is an annual or under some conditions a perennial plant belonging to the family Malvaceae. It has been cultivated in many countries throughout the world for its bast fibers, which are similar in chemical composition and properties to jute and can, therefore, be used as a jute substitute. Five varieties, comprising eight distinct types, were selected and named in India several years ago. These five varieties, which appear to be representative of the types of H. cannabinus grown in Persia, Russia, and other parts of the world, exhibit rather wide differences in the length of their growth period, in their habit of growth, and other peculiarities that are closely related to the length of the vegetative period.

This plant appears to be adapted to wide variation in climatic and soil conditions. The area under cultivation should not, however, be subject to strong winds and heavy downpours of rain. Adequate moisture should be available for the plants throughout the growing season either by natural rainfall or by planting on sites where the water table permanently remains 1.5 to 2 meters below the soil surface. Due to the fact that Hibiscus cannabinus has a taproot system with few laterals near the soil surface, the soil on which this plant is grown must be well drained and well cultivated. A sandy loam soil, high in organic-matter content, seems to be the best soil type for this plant.

The soil should be deeply and thoroughly worked in order to provide a good medium for seed germination. The seed may be sown broadcast, drilled, or planted in rows. If planted in rows, the planting distance varies from 5 to 8 inches between plants in rows from 5 to 21 inches apart, depending upon soil fertility and moisture conditions. Approximately 30 pounds of seed per acre are planted depending upon the method of seeding and the planting distance.

The crop, during the first month of growth, should be cultivated in order to eliminate weed competition, after which time the plants reach a sufficient height to shade out weed growth.

Growth of Kenaf appears to be greatly stimulated by the presence of considerable amounts of humus in the soil, which can be supplied in the form of green manure. A rotation of crops is suggested in Java, which consists of Kenaf, followed in order, by a green manure and a food crop, such as rice, corn, or sorghum.

Harvesting, which should take place while the plants are in bloom, can be done by reaping the plants with a mower, cutting them with a sharp knife, or pulling them up by the roots. The leaves and tops are stripped off in the field and the stalks tied in bundles. These bundles of stalks are then placed in retting basins and retted for about 10 days, depending upon environmental conditions and other factors. The fiber is then stripped from the retted stalks, washed, and dried. Yields are divergent, depending upon soil and environment, but generally yields of from 1,000 to 2,000 pounds per acre may be obtained.

Hibiscus cannabinus is subject to foot rot and stem diseases, the former being the most serious. Very few insect pests have been reported as attacking this plant.

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